

Human Factors in the Maintenance of Unmanned Aircraft

Alan Hobbs, Ph.D.^{*}, Stanley R. Herwitz, Ph.D.[†]

^{*} San Jose State University Foundation, NASA Ames Research Center, Moffett Field, CA. [†] Director, UAV Collaborative Center, NASA Research Park, Moffett Field, CA.

Abstract

The accident rate for UAVs is higher than for conventional aircraft. A significant proportion of these accidents are associated with human error. If UAVs are to be permitted to operate in the National Airspace System, it will be necessary to understand the human factors associated with these vehicles. Unlike conventional aircraft maintenance, UAV operators must ensure the reliability of an entire system that comprises the vehicle, the ground station, and communication equipment. At present, there have been no published studies of the human factor issues relevant to UAV maintenance. Twenty-two structured interviews were conducted with personnel experienced in the operation of small- to medium-sized UAVs. Information was gathered on critical UAV maintenance tasks including tasks unique to UAV operations, and the facilities and personnel involved in maintenance. The issues identified were grouped into three categories: hardware; software/documentation; and personnel issues. Hardware issues included the frequent assembly and disassembly of systems, and a lack of information on component failure patterns that would enable maintenance personnel to plan maintenance effectively. Software/documentation issues included the need to maintain computer systems, and difficulties associated with absent or poor maintenance documentation. Personnel issues included the influence of the remote controlled aircraft culture and the skill requirements for maintenance personnel.

Introduction

The history of unmanned aviation can be traced back at least as far as World War I (Newcome, 2004). Recent technological advances, including the miniaturization of components and other developments in the fields of electronics, navigation and telemetry, are creating new possibilities for Unmanned Aerial Vehicles (UAVs). Potential civil and commercial applications include: communication relay linkages, surveillance, search-and-rescue, emergency first responses, forest fire fighting, transport of goods, and remote sensing for precision agriculture (Herwitz et al, 2004; Herwitz, Dolci, Berthold & Tiffany, 2005).

There have been different views about the precise definition of UAVs (Newcome, 2004). For the purpose of this study, the

definition provided by ASTM International was adopted. UAVs are here defined as “an airplane, airship, powered lift, or rotorcraft that operates with the pilot in command off-board, for purposes other than sport or recreation ... UAVs are designed to be recovered and reused...” (ASTM, 2005).

Several different classification systems have been proposed for UAVs (ASTM, 2005; Joint Airworthiness Authorities/Eurocontrol, 2004; CASA, 1998). UAVs range in size from micro vehicles measuring inches in size and ounces in weight to large aircraft weighing more than 30,000 pounds. In this study, the categorization system shown in Table 1 was used.



Figure 1. Two operators prepare a small-sized UAV for flight.

The weight categories encompass fixed-wing, rotorcraft and lighter-than-air vehicles. These vehicles have a range of propulsion systems including electric and gas powered engines. Cost, complexity and capability generally increase with weight. Our initial focus in this study was on the small- to medium-sized UAVs (weights ranging from 15 to 500 lbs.). The micro and mini, and larger UAVs will be examined in the next phase of this research.

Table 1. Size class groups for UAVs

ROA Class	Weight (lbs)	Range (miles)
Micro	Less than 1	1-2
Mini	1 - 15	A few
Small	15 - 100	100s
Medium	100 - 500	100s to 1,000s
Large	500 - 32,000	1,000s

Throughout the history of aviation, human error has presented a significant challenge to the operation of manned aircraft (Hobbs, 2004). Although UAVs do not carry an onboard human, operational experience is demonstrating that human error presents a hazard to the operation of UAVs (McCarley and Wickens, 2005). Given the fact that maintenance and ground support activities appear to be responsible for a growing proportion of airline accidents (Reason and Hobbs, 2003), this human factor element will

be a critically important part of UAV operations.

To enable the operation of UAVs in the National Airspace System (NAS), it is necessary to understand the human factors of unmanned aviation. The objective of this study was to identify human factors that will apply in the maintenance of UAV systems. Maintenance was defined as any activity performed on the ground before or after flight to ensure the successful and safe operation of an aerial vehicle. Under this broad definition, maintenance includes assembly, fuelling, pre-flight inspections, repairs, and software updates. Maintenance activities may involve the vehicle as well as equipment such as the UAV ground control station.

The accident rate for UAVs is higher than that of manned aircraft (Tvryanas, Thompson, & Constable, 2005). Williams (2004) studied US military data on UAV accidents. Maintenance factors were involved in 2-17% of the reported accidents, depending on the type of UAV. For most of the UAV systems examined by Williams, electromechanical failure was more common in accidents than operator error. In a study of US Army UAV accidents, Manning et al (2004) determined that 32% of accidents involved human error, whereas 45% involved materiel failure either alone or in combination with other factors. In contrast, Tvryanas et al. and Williams found that a higher proportion of accidents involved human factors. These studies suggest that system reliability may be emerging as a greater threat to UAVs than it currently is to conventional aircraft. This trend may serve to increase the criticality of maintenance.

McCarley and Wickens (2005) reviewed the literature on human factors of unmanned aviation and identified a range of issues related to automation, control and interface issues, air traffic management, and qualification issues for UAV operators. At present, however, there have been no studies

specifically focused on the maintenance human factors of UAV systems.

Methods

Twenty-two structured interviews were conducted with UAV users from civil and military operations as part of a qualitative study. Interviewees were asked a series of questions designed to reveal human factor issues associated with UAV maintenance. The interview questions are listed in Appendix A. Site visits were conducted to selected UAV maintenance facilities. A distinction was made between manufacturers who fly and maintain their UAVs, and customers who purchased UAVs. Of the sample group, 36% were manufacturers and operators of their own UAVs. All of the civil operators were conducting line-of-sight operations.

Results

Issues that emerged from the structured interviews are arranged in three sections based on the SHEL model (Hawkins, 1993). Hardware issues are human factors that relate to the interaction of maintenance personnel with the physical structures of the UAV system. Software/documentation issues concern the interaction of maintenance personnel with computer systems and written documentation. The last section deals with personnel issues including the skill levels of maintenance staff.

Hardware

Packing and transport. Operators reported that transport and handling damage “ramp rash” are significant issues due to the need to move and assemble UAVs. The handling of UAVs is similar to sailplanes that are typically moved in trailers. One UAV manufacturer actually used the maximum size of a UPS box as a point of reference for designing their UAVs. A Sports Utility Vehicle or van may be used for the

smaller UAVs, but when wing spans start to exceed the dimensions of such a ground vehicle, then new packaging and human factors must be addressed.

Assembly. Small- and medium-sized UAVs are generally disassembled between flights for transport and storage. A particular concern is the frequent connection and disconnection of electrical systems, which can increase chances of damage and maintenance errors. One advantage of UAVs compared to conventional aircraft is that they are not generally stored outdoors where they would be exposed to threats from the elements.

UAV-specific elements. UAV systems may include unique components such as launch catapults, autonomous landing systems, sense-and-avoid instrumentation (ground-based or airborne) and flight termination systems (e.g. parachute release; engine kill).

Battery maintenance requirements. Batteries were noted as the cause of a high proportion of mishaps, both with the airborne and ground-based systems. Careful attention needs to be directed to battery charging/discharging cycles. In addition, some types of batteries (e.g., lithium polymer) can be dangerous if correct procedures are not followed.

Composite materials. UAVs tend to make extensive use of composite materials. Repair of these materials may require special expertise and equipment to deal with hazardous materials.

Distinguishing between payload and aircraft. In contrast to conventional aircraft, the payload on board a UAV is more likely to be integrated with the UAV structure and power supply. Maintainers may be expected to support the payload as well as the aircraft.

Salvage of UAV and associated hardware. UAVs often experience operational-related damage (e.g., hard landings; contact with water). Maintenance personnel will be required to make judgements about the reuse and salvage of components involved in such occurrences.

Repair work by UAV manufacturer. The small size of many components and the modular approach to many UAV designs enables operators to ship damaged components back to the manufacturer for repair. A trend was detected indicating that minor maintenance was performed by operators, but major repairs generally involved sending the UAV back to the manufacturer.

Absence of information on component failure modes and rates. The manufacturers of components used in small UAVs generally do not provide data on the failure modes of their components and the expected service life or failure rate of these components. This absence of information is particularly notable for components purchased from Radio Control (RC) hobby shops. In the absence of service life information, reliability-centered maintenance programs cannot be developed (Kinnison, 2004). For example, there is little information on the service life of servos designed for radio controlled aircraft, and now being used in UAVs (Randolph, 2003).

Recording of flight hours. UAVs do not generally have on-board meters that record airframe or engine flight hours. If this flight history information is not recorded by the ground station, the timing of hours flown must be recorded manually for maintenance purposes and inspection scheduling.

Lack of part numbers. Non-consumable UAV parts that can be removed and repaired (i.e., rotatable components) generally do not have part numbers. Tracking the maintenance history of

these components may become problematic, and may increase the risk of maintenance errors.

Unconventional propulsion systems. An increasing number of UAV designs propose the use of emerging technologies. Interviewees could not provide detailed information on the maintenance requirements of technologies such as fuel cells, solar power systems, and electric engines.

Fuel mixing. Unlike conventional manned aircraft, some UAVs require fuel to be mixed on-site. This task is typically performed by the UAV operator/maintainer rather than by dedicated refuelers. Human error during the handling of fuels may result in health and safety, and airworthiness hazards.

Software/documentation

Extensive use of computers. Virtually all UAV systems rely on laptops as the basis for flight control. Given the importance of computer components, several UAV owners require maintenance personnel to have an understanding of software and the capability to make software updates.

Autopilot software management. Maintenance personnel may need to update UAV autopilot system software, and then verify and clearly document the software versions being operated.

Availability of flight history data. UAV ground stations commonly record flight history such as engine performance. These data are useful for evaluating performance and identifying anomalous conditions. UAV maintenance personnel will require the ability to interpret such data.

Lack of maintenance documentation. Several operators reported that UAVs were delivered with operating manuals, but no maintenance

manual or maintenance checklists. As a result, the operators had to develop their own maintenance procedures and documentation. The need for well-prepared documentation is highlighted by the fact that several customers purchased UAVs without technical information such as wiring diagrams.

Poor standard of maintenance documentation.

In cases where a UAV was delivered with maintenance documentation, maintenance personnel were sometimes dissatisfied with the quality of documentation. For example, UAV maintenance documents rarely, if ever, conform to the ATA chapter numbering system. In the course of the interviews, examples were given of poor procedures including poorly conceived Fault Isolation Manual (FIM) documents. One of the most common recommendations was the need to keep careful log books that document all tasks performed on the UAV.

Personnel issues

Complacency. Aware that there is no human on board the aircraft, there is a potential for maintenance personnel to become complacent, particularly with regard to deviations from procedures.

Model aircraft culture. The most commonly cited skill sought for UAV maintenance was experience with RC planes. Such personnel, however, do not necessarily reflect a mainstream aviation background. Some RC hobbyists may be accustomed to operating without formal procedures or checklists.

Lack of direct pilot reports. UAV maintenance personnel do not receive log book entries describing problems detected by an on-board pilot during flight. For manned aircraft flights, the pilot's log book entries are an important source of information for maintenance personnel (Munro, 2003). Although flight history may be recorded in the UAV ground control station and reports may be made by the

ground-based UAV operator, these reports will not contain any information on a pilot's direct sensory experience of the aircraft's flight performance.

Operator and maintainer may be same person.

A primary attraction of UAV technology is the ability to operate the vehicle with a small number of multi-skilled individuals. For small UAV operations, maintenance tasks tend to be performed by the operator.

Need for wide skill set. Small operators expect maintenance personnel to possess skills in a wide range of fields, including electrical and mechanical repairs, software, and computer use. Given the potential risk of electromagnetic interference (EMI), another fundamental requirement is an understanding of radio transmission, wireless communication, and antenna electronics.

Discussion

A key finding was that UAV maintenance requires attention not just to the aircraft, but to the entire system, including the ground control station, wireless communication links, sense-and-avoid instrumentation, and, in some cases, specialized launch and recovery equipment.

This study identified tasks that are unique to UAV maintenance, representing new challenges for maintenance personnel. These tasks include transport and assembly of the vehicle and associated systems, and pre-flight ground tests necessitated by the assembly of the aircraft at the flight location. The work of a UAV maintenance technician involves a broader range of tasks than those involved in the maintenance of conventional aircraft.

The diversity of UAV systems is typical of the early development stage of any new technology. The scope of maintenance activities ranges from repairing a small military UAV with duct tape to major work on complex

vehicles necessitating return to the manufacturer. The maintenance requirements for a 5 oz. micro air vehicle cannot be equated with those for a 32,000 lb. Global Hawk.

The interviews conducted thus far have been confined to manufacturers and operators of small- to medium-sized UAVs. The conclusions reached apply to these sectors of the industry.

The ability to ship components or even entire aircraft to the manufacturer for maintenance will have significant impact on the way maintenance is performed. It appears that major maintenance or major checks will be performed by the manufacturer, while the operator will attend to routine preventative maintenance and minor corrective maintenance. An increased trend towards modularity and “repair by replacement” may enable maintenance to be performed by personnel with a lower level of expertise than would be required if components were repaired in the field.

Human factors in conventional aircraft maintenance include time pressure, insufficient knowledge and skills, procedure design and coordination difficulties (Hobbs and Reason, 2003). The maintenance of UAVs involves not only these issues, but also additional challenges. The reliance on laptop computer for UAV operations means that the support and maintenance of a computer system and associated software is now an airworthiness task. As a result, human-computer interaction and computer system knowledge will be important human factors considerations for UAV maintenance personnel.

Several findings related to information management. Issues such as the lack of maintenance documentation, the poor quality of existing documents, a lack of formalized checklists and the absence of parts numbers are potential error-producing conditions.

Cultural issues also were identified as a potential area of concern. Many UAV maintenance personnel have a background in

RC aircraft, and they may bring expectations and norms that differ from those in conventional aviation.

The driving force behind the UAV industry is affordability and the need to minimize the number of personnel involved in UAV operations.

This driving force creates a pressure as well as an incentive to staff UAV operations with a small group of individuals. Although the trend towards modularity will reduce the need for complex maintenance in the field, the view was expressed that maintenance personnel will nevertheless require a wide range of skills. Key skills widely cited by the interviewees included knowledge of electrical and mechanical systems, radio communication, and an understanding of software upgrades and documentation.

During the interview process, it became apparent that there are two schools of thought regarding the maintenance of UAVs. One view is that the aircraft and control station must be maintained at the same standards as conventional aircraft. The other view is that small and medium-sized UAVs comparable in size to RC planes can be maintained to a different standard than conventional aircraft.

The next phase of this study will provide more attention to the extremes of the UAV industry as defined in Table 1 (i.e., micro, mini, and large UAVs). In future reports, specific attention will be given to the knowledge and skills required to perform UAV maintenance, the facilities required, and human factors training requirements.

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Appendix A: Interview structure.

1. Provide a general description of vehicle and operations.
2. Who performs maintenance?

3. What are the key maintenance tasks? Ground support tasks?

4. Are there maintenance tasks unique to unmanned aircraft? Are these tasks different to those in maintenance of RC aircraft?

5. Are there particular maintenance problems associated with your operation?

6. Special facilities needed?

7. What qualifications, skills and training are needed to perform maintenance? If you were advertising for a UAV maintenance person, what skills and experience would you be looking for?